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SHORT TERM TASK FINAL REPORT

IMPROVED MARKER MAKING

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This project addresses the potential for developing computer systems which will significantly add to the efficiency of developing a pattern layout on a length of fabric, commonly referred to as a marker.

This report documents monthly progress on the technical and cost analysis of improved marker making systems.

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Abstract

The apparel industry has focused in recent years on improving its responsiveness to the marketplace as a means of increasing the industry's competitiveness with overseas manufacturers. One aspect of efficient market response is the marker making process. This paper reports the results of a 12-month study undertaken at Georgia Tech to determine the technical and economic feasibility of improving the state-of-the-art in marker making systems for the apparel industry.

Tech researchers have concentrated on three primary areas in performing this study. The initial effort involved contacting commercial vendors of software systems which address the marker making problem. These vendors participated in a survey designed to determine what capabilities exist in current software packages. In addition to talking with the vendors, researchers visited users of the software of each of the participating vendors. These visits allowed for a more unbiased view of the software packages. The next line of pursuit entailed an extensive literature search and analysis of the optimization problem known as the cutting stock problem. Other pertinent literature was studied for both the technical and economic aspects of the project. The final part of the study was to explore new ideas for future research in the marker making problem. Each of these areas are discussed in detail in this report. The discussion focuses first on the technical issues, and then moves to the economic issues. Conclusions and recommendations appear in the final section of the report.

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1. Background and Objectives

The apparel industry has focused in recent years on improving its responsiveness to the marketplace as a means of increasing the industry's competitiveness with overseas manufacturers. One aspect of efficient market response is the marker making process.

A *marker* is an arrangement of garment pattern pieces on a length of fabric. where none of the pieces is allowed to overlap. *Marker making* is the process of producing such arrangements of patterns. Many companies today still execute the marker making process by hand. This means that all pattern pieces must be drawn out on paper, cut, and placed in the arrangement in which they will be cut on the fabric spread. For markers with large numbers of pieces, this means that the marker maker never sees the entire marker, and loses that perspective from which to make improvements to the marker.

There are generally many constraints to consider in the marker making process. Gordon (1989) summarizes these as follows:

1. *Nap* constraints -- All pieces to be sewn together should be placed in the same direction.

2. *Tilt* constraints -- Limit the degree to which a part may be tilted within the marker.

3. *Flip* constraints -- Applied when pieces cannot be flipped.

4. *Stripe/Plaid* constraints -- Applied when the fabric contains stripe or plaid lines which must be matched in the sewing of the garment.

5. *Cutting* constraints -- Needed when certain pieces must be placed far enough away from pieces to attain quality cutting.

6. *Shading* constraints -- Required when pieces to be sewn together must be cut from the same region of the fabric spread.

What then constitutes a *good* marker? Any marker which satisfies the applicable constraints as described above, and minimizes fabric waste is a good marker.

There do exist certain patterns whose characteristics can be exploited to improve fabric utilization. Certain types of pieces can be placed in any orientation with respect to the

boundaries of the fabric spread. (This is a complete relaxation of the tilt constraint for certain pieces.) Also, advantage can be taken of the ability to flip certain pieces either independently or in affiliation with the other pieces to which these will be sewn. Some pieces may be split to fit into a marker more efficiently, or in some cases, (such as when tubular goods are used) pattern pieces can be folded and placed along the edge of the fabric. Manipulation of these special characteristics, when applicable, can be used to increase fabric utilization.

Clearly, the manual marker making process is quite a difficult one, both in terms of labor intensiveness, level of skill required, time requirements, and marker quality (based on both fabric utilization and meeting marker constraints). Fortunately, manual methods are no longer required.

The technology of marker making has improved dramatically over the last decade. The state of the art system now allows the operator to mark pieces on the fabric to be cut on a computer screen while trying out different configurations to achieve the best overall utilization of the fabric. Patterns from the designers are converted to digital representations and stored electronically, and the markers are transferred digitally to cutters. The software also helps the operator by checking for errors and keeping track of the parts produced and needed.

Computer hardware and software technologies have advanced to the point that the marker making process has been extensively streamlined. Some people even refer to these computerized systems as "automatic marker making." We will be very precise in our usage of the term *automatic*. Automatic markers are those computer-generated, production-worthy markers produced *without* the intervention of a human operator. Using this definition, today's computerized systems *are not* automatic. These systems can best be described as computer-aided design (CAD) systems, where the human operator interacts with a graphical interface to create the marker electronically. This electronic data is then transferred to a plotter where the actual marker is drawn out on paper. This paper marker can then be physically transferred to the cutting table. In cutting rooms having automated cutter the plotting step is no longer a requirement. The electronic marker can be transferred from the computer where it is generated directly to the automatic cutter.

Some of the apparel CAD system suppliers do offer "automatic marker making." These special packages generally use very simple rules to generate markers automatically, with no aid from the operator. Since nothing very clever is being done in these packages to solve the

problem, the systems cannot consistently outperform the human being with respect to fabric utilization.

However, there are situations where quick but reasonably accurate estimates of fabric utilization are required or where automatic marker making matches the efficiency of the human operator. An example is the men's tailored clothing area, in particular, made-to-measure suits (see Gordon, 1989). The nature of this specialized product allows the automatic marker maker to match the efforts of the human operator. A second area of successful application is in the area of costing. Even the inaccurate results of an automatically produced marker are closer to true fabric utilization than most "guesstimates". This is especially true since in many applications, the automatically produced marker achieves a fabric utilization fairly close to that of a human operator.

The primary objective of this research project has been to determine the technical and economic feasibility of developing marker making systems whose performance will exceed that of existing systems; in particular, the development of *automatic marker making systems*. According to Gordon (1989) an ideal automatic marker making system should have the following characteristics:

1. Be consistently as efficient as possible (i.e., maximize fabric utilization).
2. Conform to all applicable marking constraints.
3. Exploit special pattern characteristics to improve marker efficiency.
4. Execute as quickly as production flow demands.
5. Be cost effective with respect to computational requirements.

Unfortunately, there are no systems on the market today that satisfy all of these criteria. Much work remains to be done before such a system can come to realization. This report will present the details of the technical and economic feasibility study conducted by the research team, and specify conclusions and recommendations for further research in this area.

The remainder of this report will be divided into three sections: Technical Analysis (2), Economic Analysis (3), and Conclusions and Recommendations (4). Section 5 will contain a list of references used in compiling this report. Appendices are attached at the end and are referenced in the text which follows.

2. Technical Analysis

2.1 Introduction

The technical part of this study has concentrated on three key areas. Initially, the work focused on commercial vendors who market software (and hardware) systems for processing the marker making problem. Vendor participation was solicited, a survey was constructed and administered to these vendors to determine the composition of the state-of-the-art technology, and users of these commercial systems were visited to get a more practical view of the software. This part of the study is discussed in section 2.2. Another large component of this study is directed at an analysis of the underlying optimization problem, known as the *cutting stock problem,* with respect to marker making. An extensive literature review was performed, from which specific conclusions have been made. This review and analysis is presented in section 2.3. The final phase of the study looked into new techniques for marker making and suggestions for future research. Two such possibilities, expert systems and neural networks, are discussed in section 2.4.

2.2 Views from Vendors and Users of Existing Systems

2.2.1 Existing Software -- Vendors

Georgia Tech was able to solicit participation from three commercial vendors of marker making software systems. Although no vendor will be mentioned by name, Georgia Tech, Southern Tech, and DLA are appreciative of the time and cooperation given by these companies to this project. A letter of appreciation has been sent to these vendors, along with a copy of this report.

These companies were engaged to answer a survey, constructed by the researchers, which was designed to obtain various information pertinent to their software. Topics included hardware required, training necessary to operate, marking constraints observed by the software, special features, level of automation, and performance information. The survey questions are attached to this report as Appendix A. The results of this survey are summarized below.

All of the vendors surveyed provide software which will run in a DOS-based PC environment. All suggested a system based minimally on the 80286 microprocessor for better execution time. Cost ranges for software costs range from less than $10,000 to $25,000. One company offers a complete turnkey system including all hardware and software for $50,000 to 55,000. Various peripherals which work with the basic computer (some of which are required)

include a digitizer, a plotter, a printer (some systems can use a laser printer), a graphics display mouse, and VGA graphic displays.

All vendors provide training both at the company location and on-site (some at no charge, some for rather hefty fees). One company offers a training video. Training topics include basic computer operation, pattern digitizing and grading, actual marker making, and outputs. Duration of training varies from three days to two weeks or more. Phone support is also provided, as well as software upgrades.

With regard to constraints, all companies provide for the usual marking constraints: nap, tilt, flip, and pattern matching. In all cases these constraints are applied by default unless overridden by the operator. Two companies also provide for such constraints as rotation, overlap, and pattern splitting. None of the commercial packages can offer the operator suggestions as to the placement of pattern pieces. However, other special features included handling of tubular goods, blocking features (enlarge a piece for pattern matching or dye blocking for dye cutting), specifying alteration on the marker, and dynamically altering pieces during marker making (made-to- measure).

The next part of the survey dealt with the level of automation available in the commercial software. One company (Co. A) has no automatic mode for producing markers; the mode is strictly interactive. It should be noted, however, that this package is the least expensive of the three and operates in a friendly, pull-down menu, window mode. A second vendor (Co. B) has an intermediate automatic mode. The system is basically interactive, but does have the ability to produce a marker with no operator intervention, by methods described as heuristic. The completely automatic mode can be interrupted by the operator. The third company (Co. C) currently seems to have the most sophisticated automatic mode. It offers two approaches, one described as heuristic* and the other described loosely as an expert system. According to the vendor, the most sophisticated version of the software has the ability to teach the system to lay a marker by a certain technique.

Both respondents of companies B and C said that their automatic modes could not beat the operator with respect to average fabric utilization, although Bs respondent said their system was only 1 percent to 2 percent worse. Cs respondent said that their expert system technique could produce better markers than the operator, but gave no average performance numbers. Both B and C respondents agreed that a marker can be produced automatically in about half the time (on average) required by the human operator. Both companies are continuing to work on making improvements

* A heuristic method is an algorithm which is designed to find a very good feasible solution, but not necessarily a mathematically optimal one.

to their automatic modes. Company A is currently working on including an automatic system within the next year.

When questioned about the length of time required to make a marker, the vendors mentioned such complicating factors as the number of pieces in the pattern, complexity of the pieces, how many sizes are included in the marker, how restrictive the marking constraints are (i.e. whether they exist and, if so, how tight they are), type of garment, and variability in the area of pattern pieces.

The vendors all seem confident that improved systems are just around the corner and that improvements can be well-justified by using automatic markers in the costing of a garment, by deskilling the process so training can be effected in short periods of time, and by the faster turnaround time of an automated process.

2.2.2 Existing Software -- Users

As a part of the examination of existing software, user sites were visited, one for each of the participating vendors. The individuals at these plants were most gracious and accommodating to our needs, taking several hours from their busy schedules to talk with us and demonstrate how they were using the software system. Letters of appreciation have been sent to these companies, along with a copy of this report. Note that many of the details of these site visits are reported in section 3 (Economic Analysis) as most of the information we obtained from the users was more germane to that aspect of the study than to the technical side.

These marker making systems all use high resolution graphics and pointing devices to aid the operator in producing better markers. This technology is still new enough that all the users remember the days of manual marker making. (In fact, many companies today still perform this task manually). So a common note of enthusiasm was observed at all three user sites for the effectiveness of the current CAD systems. When questioned about their "wish list" for improvements, all mentioned only simple things that could easily be accomplished with minor programming changes. These included the ability to modify an existing marker, or links between style changes and existing markers so that every marker using that style didn't have to be upgraded.

All users agreed that automatic marking would be a great benefit, but none was using what is now provided. In fact, one user called it a "waste of time." General comments about the usefulness of such an automated system include those things that have already been mentioned: costing of garments, deskilling the task so that a company is not so dependent on the presence of a marker maker, and improved processing time.

2.3 The Cutting Stock Problem

2.3.1 Introduction and Problem Description

In the introduction to this paper, a marker was defined as an arrangement of garment pattern pieces on a length of fabric. This problem is a variation of the classical optimization problem known as the *cutting stock problem.* This problem can be stated mathematically as follows (see Hinxman, 1979):

Given is a set of integers $\{d_1, d_2, ..., d_n\}$ representing the number of pattern pieces of each size to be arranged in the marker. The object is to minimize the total cost of the fabric consumed in satisfying the marking constraints while accommodating all the requirements of the order itself. Let the sizes to be cut be numbered i (i = 1, 2, ..., n) and let the sections to be used be numbered j (j = 1, 2, ..., m). Let c_j be the fabric cost for section j and a_{ij} the number of pieces of size i to be cut from section j. The problem is then stated as:

$$\text{Minimize} \quad \sum\nolimits_{[j=1..\mu]} c_j$$

subject to the conditions that

$$\sum\nolimits_{[j=1..m]} a_{ij} = d_i \qquad \text{for } i = 1, 2, ..., n$$

$[a_{1j}, a_{2j}, ..., a_{nj}]$ correspond to a feasible cutting pattern for section j, j = 1, 2, ..., m according to the applicable marking constraints.

When overruns or underruns are allowed, the equality constraints are replaced by the inequalities

$\sum\nolimits_{[j=1..m]} a_{ij} \geq d_i - u_i$ and $\sum\nolimits_{[j=1..m]} a_{ij} \leq d_i + v_i$ where u_i is the maximum underrun and v_i is the maximum overrun allowed for size i.

This problem is a very difficult one, even if the cutting pattern constraints are not restrictive and the pattern pieces are very simple (e.g., see Farley, 1989 or Rinnooy Kan, et al., 1987). Much work has been done in the past 30 or so years in attempting to find acceptable solution methods for the basic cutting stock problem and its variations. A review of this work is given in the next two sections. Implications of cutting stock problem research for the marker making problem are discussed in the third section following.

2.3.2 One-Dimensional Cutting Stock Problem

An illustration of the one-dimensional cutting stock problem is the cutting of steel bars of length L into orders for pieces of lengths $\{l_i; i=1,...,m\}$. Other dimensions of the stock pieces (the steel bars) are irrelevant to the solution (e.g. how thick the bars are). The problem is to select as few of the steel bars as possible to use in cutting the i pieces required to fill the order. To do this, one might examine all possible patterns of cutting one steel bar into required lengths. These patterns are then combined in an optimal way so that demand is satisfied. It turns out that this simple scheme can be very difficult to carry out.

Consider a standard roll of paper 200 inches long which must be cut into 40 different lengths ranging from 20 inches to 80 inches. The number of cutting patterns could easily exceed 100 million! (See Gilmore and Gomory, 1983). This is an example of a combinatorial optimization problem for which there are no known solution procedures which execute in polynomial time (Karp, 1972). This means that as the problem size grows, the length of time for an optimal solution to be found has an exponential growth rate. As a result, problems of this nature which must be dealt with in practical situations are generally solved by heuristic methods. Thus, means that in lieu of finding an optimal solution, solution methods find answers in a reasonable amount of time and the answers are accepted as "good enough."

The work most often cited for the one-dimensional problem, and the method giving the best results, is that of Gilmore and Gomory (1961, 1963). Their approach is to find near-optimal solutions based on the linear relaxation* of the cutting stock problem, rounding the answers to the nearest integer solution. The method is based on column generation (each column representing a different cutting pattern) and developing an efficient method for solving the auxiliary problem, which is a knapsack problem**.

Not much work was done in this area for several years following the Gilmore and Gomory paper. Haessler (1974) develops a formulation of the one-dimensional problem with a setup cost for using a cutting pattern and devises a heuristic to balance the conflicting objectives

* The *linear relaxation* of an integer program is the identical mathematical program except for the variable values. For example, in a 0-1 integer program the variables can either be 0 or 1. In the linear relaxation the variables can take on any real value in the interval [0,1]. Linear programs are, in general, much easier to solve than integer programs.

**The description of the *knapsack* problem is as follows: Given a set of items which must be packed into a knapsack, choose the items (each of which have been assigned a value) so the total value of the items in the knapsack is maximized and the capacity of the knapsack is not violated.

of minimizing both trim loss and pattern changes. Golden (1976) reviews solution methods for the problem, discussing the Gilmore and Gomory approach, as well as integer programming, and combinatorial heuristics. He suggests subgradient optimization as a viable heuristic technique as well.

Marcotte (1985) shows that certain classes of one-dimensional cutting stock problems can be solved optimally by finding the linear programming solution and "rounding up" to the integer solution required by the cutting stock model. The importance of this paper is that it provides insights into why the Gilmore and Gomory approach works so well and establishes a basis for further work in exploring the relationship between the cutting stock problem and its linear relaxation.

Seth, Prasad, and Ramamurthy (1986) claim that too much wastage results from the "linear programming round-off" method is used. They develop a new heuristic based on a modified objective function which accounts for reusing the initial wastage. Computational results indicate good results.. Roodman (1986) presents a practical application where the linear programming round-off method turns out to be highly unreliable. Special restrictions include the necessity for small numbers of relatively long cuts, cutting as few pieces as possible, and limited raw material inventory. His empirical results indicate the heuristic is efficient and effective. Finally, Farley (1988) modifies the Gilmore and Gomory approach to incorporate additional objectives, such as initial pattern generation, explicit valuation of undersupply and oversupply, and waste having a positive value.

At this point the reader may be wondering why this section has been included when the marker making problem is clearly *not* a one-dimensional problem. However, solutions to higher dimensional problems can often be found either by modifying a method from a lower dimensioned problem, or by incorporating basic methods from a lower dimension into subroutines in the higher dimensional problem solution. Thus, this presentation of methods for the one-dimensional problem will facilitate the discussion given in the following section.

2.3.3 Two-Dimensional Cutting Stock Problem

Perhaps the most important thing to note about previous research on the two-dimensional problem is that it is almost always concerned with *fitting rectangles into larger rectangles*. Such existing methods would be applicable only to markers made at a handkerchief factory! This means that any of the results presented must (at minimum) be modified before application can be made to the marker making problem found in the apparel industry. This

problem is even more difficult to solve than the one-dimensional problem, and adding the irregular shapes of the pattern pieces required in the apparel industry only complicates the problem further. And if that isn't enough complexity, the marking constraints discussed in section 2.3.1 make the development of a standard solution methodology very difficult indeed.

To clarify the discussion below, several terms need to be defined. This can best be done by referring to the illustrations in figure 2.1. *Guillotine cuts* (A) are made when the section is cut entirely from one side to the other, one or more times. In figure 2.1, only one guillotine cut has been made. *Non-guillotine cuts*(B) mean that no cut is made which spans the section entirely from one side to the other. Non-orthogonal cutting (C) means that one or more pieces are tilted with respect to the horizontal and vertical boundaries of the section. In the discussion which follows, it is assumed, unless otherwise stated, that each paper deals with arranging rectangles within rectangles and that the objective is minimizing fabric waste.

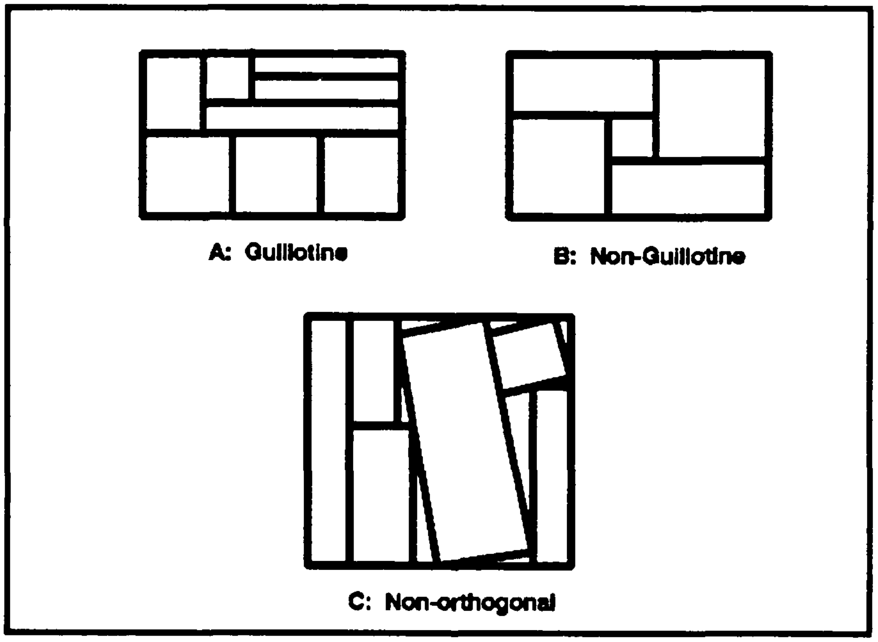

Figure 2.1 Various types of cuts

Gilmore and Gomory (1966) are again the most cited researchers for the two-dimensional problem. Their approach to this problem is an extension of their solution method for the one-dimensional problem. Their method is not as general for the 2-D problem because of difficulties

in solving the auxiliary knapsack problem. However, they show that when cutting is done in stages*, the method is viable.

Barnett and Kynch (1967) consider a very simple problem where the pattern pieces are of unit width and equal length (or no more than two different lengths). They present an optimal algorithm for this special case.

Hinxman (1980) gives a nice discussion of both the one- and two- dimensional problems, along with a review of the work that had been done at that time. The methods are divided into two groups: algorithmic and heuristic. He states that the heuristic methods are highly "domain dependent"; i.e. even apparently similar problems may require radically different heuristic techniques.

He distinguishes the cutting stock problem from the knapsack problem. In a knapsack problem each of the order pieces is given a value and the objective is to maximize the total value of the pieces to be cut from a stock item. In the cutting stock problem, the order list describes the number of pieces of each size that must be supplied (e.g., pants fronts, pants backs, front pockets, etc. and the sizes associated with each of these). The objective is to minimize the total cost of the stock items consumed in satisfying the orders.

Hinxman goes on to say that the algorithmic methods (i.e. those which are optimizing) fall mainly into the categories of linear programming, branch and bound, and dynamic programming. The heuristic methods can be classified as *cut-off* heuristics (an example would be to stop a branch and bound* search before optimality is reached and return the best solution so far), *using an existing cutting pattern repeatedly* (repeated exhaustion reduction), *sampling* (an example is column generation), and *value heuristics* (where the objective is to maximize some total of the values assigned to each order piece).

* Cutting in stages occurs when a piece of material being cut must be cut all the way through from one edge to another. The resulting smaller pieces may then be treated separately and cut again, but again each is cut all the way through. The cutting patterns produced in this way will still be intricate and tremendously numerous, but this replacement of the original multidimensional problem with what is called a *multistage problem* leads to methods of solution (see Gilmore and Gomory, 1966).

* *Branch and bound* refers to an exact solution procedure where the solution space is constructed in the from of a tree. This tree is searched by *branching* on its various limbs. The search is limited by computing upper and lower bounds on the optimal solution by solving subsidiary problems which give the desired bound. See Hillier and Lieberman, 1986, for a basic explanation of this technique.

Hinxman concludes by saying that the state of the art is such that anyone faced with a cutting stock problem is likely to need to develop his own heuristic method, unless the Gilmore and Gomory approach is feasible.

Cochard and Yost (1985) describe a specialized application and heuristic development for improving the utilization of cargo space on U.S. Air Force cargo aircraft. They develop an interactive system which relies on a modified one-dimensional algorithm.

Harrison (1986) presents four criteria which can be used to judge the quality of a marker. These criteria are:

1) Markers are required to have acceptable levels of waste (instead of minimal).

2) A section must be started and completed on the same marker.

3) Marker run lengths should be as high as possible.

4) Markers that result in small quantities of pieces not yet arranged should be avoided.

These four criteria could be (and often are) used as rules of thumb by real-world marker makers in building actual markers.

Rode and Rosenberg (1987) analyze six simple polynomial algorithms for the 2-D problem and compare them based on fabric utilization. All the algorithms require using only guillotine cuts to be used.

Qu and Sanders (1987) introduce an automatic algorithm for nesting of regular and irregular shaped parts whose shapes are approximated by composites of non-overlapping rectangles. Their algorithm failed to perform better than an experienced operator. The application area is the metal fabrication industry.

Dagli and Tatoglu (1987) deal with 2-D pieces on rectangular stock of finite dimensions. They mention several restrictions, but only incorporate the need for finite cutting tolerance. The shapes can have sides defined by line or arc segments. They use rectangular approximations of the irregularly shaped pieces to get a rough approximation, and then fine tune using simple heuristics (e.g., place maximum area pieces first). They conclude that none of these simple heuristics dominates. Their computational results show good performance.

A heursitic designed for a cutting stock problem in the furniture industry is described by Voight (1987). He implements a linear programming-based algorithm in a PC computing

environment. In addition to strictly solving the marker making problem, he attempts to tack on ways to minimize the amount of labor needed for the actual cutting.

Rinnooy Kan, De Wit, and Wijmenga (1987) describe an approach based on the knapsack problem where non-orthogonal cuts are allowed. Schneider (1988) describes an application in a crepe-rubber mill. He compares heuristic and optimal solutions to the problem where only guillotine cuts are allowed and the cuts must be made in a certain order. His computational results seem good.

The only paper found which deals with the cutting stock problem in the apparel industry is by Farley (1988). He points out the practical difficulty of enclosing most pattern pieces within a rectangle, eliminating the possibility of patterns designed totally by a computer-based algorithm or heuristic. He recognizes that in this application fabric utilization is often not the only objective. In fact, he attempts to model a broad planning problem which includes the marker making problem as only one component. He focuses on using mathematical programming to improve factors such as planning and turnaround time.*

An application in the glass industry is presented by Madsen (1988) where traveling salesman routines are used to solve the marker making problem when it is important that an individual orders be kept relatively close together in a production run.

There are many practical applications of the two-dimensional cutting stock problem. These include such industries as paper, glass, and sheet metal, for which the problem is indeed fitting rectangles into larger rectangles. However, for industries such as the furniture upholsterer, the shoe manufacturer, and the apparel manufacturer, the problem becomes even more complex due to the irregularity of the pattern pieces which must be arranged within the markers. The implications of research on the cutting stock problem for the apparel industry are discussed in the next section.

2.3.4 Implications for the Marker Making Problem

There is no obvious solution to the cutting stock problem in general, and thus no obvious solution to the marker making problem. Optimization can be a very valuable tool, however, and there may be new approaches which have not yet been attempted or adaptations of

* The *traveling salesman problem* is a classical problem from operations research for which many solution procedures have been developed. The problem consists of a set of cities each of which must be visited once and only once (thus the name traveling salesman problem). The objective is to construct such a tour of the cities so that its length is as short as possible.

existing methods which could lead to satisfactory techniques for "automatic" marker making. This is especially true if an expert system is also to be applied to the problem (see section 2.4.1).

For example, one method mentioned frequently in the literature is to use a rectangular approximation for irregularly shaped pattern pieces. Instead of using just one rectangle, a much better estimation of the irregular shape can be found by using several rectangles to achieve this approximation as shown in figure 2.2. Note: this figure is taken from Qu and Sanders (1987).

Therefore, even though the literature paints a grim picture of using an optimization approach for finding an "optimal" solution to the marker making problem, optimization still has value in achieving more effective automation in the marker making process.

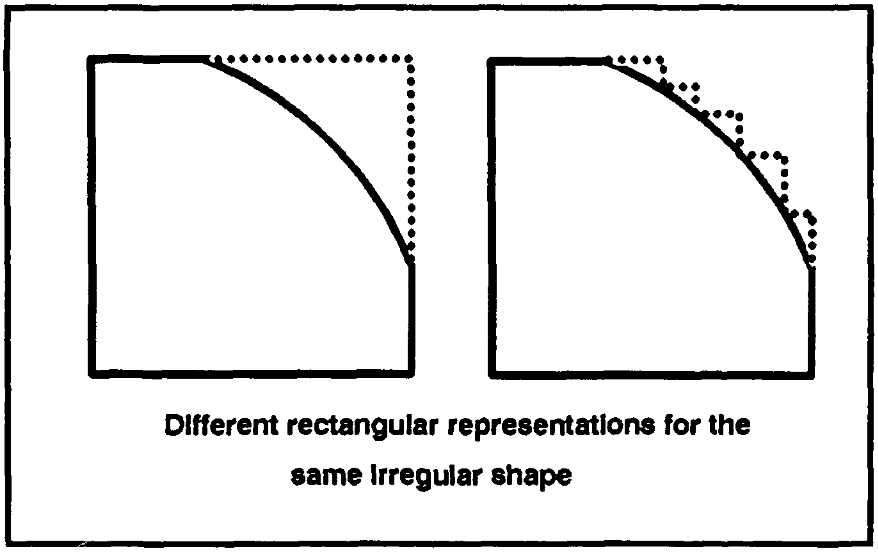

Figure 2.2 Two representations of an irregular shape with rectangles

2.4 Other Approaches

While there may be many new and unexplored approaches to solving the marker making problem, only two will be discussed here. Most of the past effort in improving the marker making process has been focused on adapting methods to fit existing computer technology to solve this very difficult problem The fact of the matter is that today's computers are not well suited to pattern recognition tasks (Gordon, 1989). Unlike electronic processors, the human mind excels at pattern recognition. Thus, the two approaches presented here, expert systems and neural networks, both attempt to mimic the human mind.

2.4.1 Expert Systems

Expert systems were first introduced as a successful approach to solving very complex problems in the late 1970s and early 1980s. A very broad definition of an expert system is a computer program designed to solve a problem which is fairly narrow in scope and which emulates the decision-making process of a person considered to be an expert in the field. Expert systems have been applied to problems in areas such as medical diagnosis, managing the manufacture and distribution of computer systems, performing cartography (or map labeling), and inferring the 3-D structure of a protein from an electron density map (Harmon and King, 1985).

Professor Edward Feigenbaum of Stanford University (see Harmon and King, 1985) has defined an expert system as:

> ". . . an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. Knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field.
>
> The knowledge of an expert system consists of facts and heuristics. The 'facts' constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The 'heuristics' are mostly private, little-discussed rules of good judgment (rules of plausible reasoning, rules of good guessing) that characterize expert-level decision making in the field. The performance level of an expert system is primarily a function of the size and the quality of the knowledge base it possesses."

The question here is whether an expert system approach will work for the marker making problem. Waterman (1986) provides a set of questions which addresses this important issue. If

positive answers to these questions can be obtained, then one can proceed with the development of an expert system for the problem domain under consideration. These questions are presented and discussed in the following paragraphs.

A. When is expert system development possible?

Figure 2.3 summarizes the domain characteristics required to make expert system development possible. If all of these requirements are met by the marker making problem, this question can be answered affirmatively. These requirements are presented as statements:

1) Marker making is not dependent on common sense.

2) Marker making requires only cognitive skills.

3) Marker making experts can articulate their methods.

4) Genuine marker making experts exist.

5) Marker making experts agree on solutions.

6) The marker making task is not too difficult.

7) Marker making is not poorly understood.

Each of these statements can be construed as true. The marker making task can be taught by the transfer of cognitive skills and good solutions are not obtained by applying common sense, but rather by applying the cognitive skills and "rules of thumb" that are passed from one marker maker to another. During the course of this research, discussions have been held with true experts. From these conversations and from the literature, statements 3 and 5 through 7 can be assessed as true.

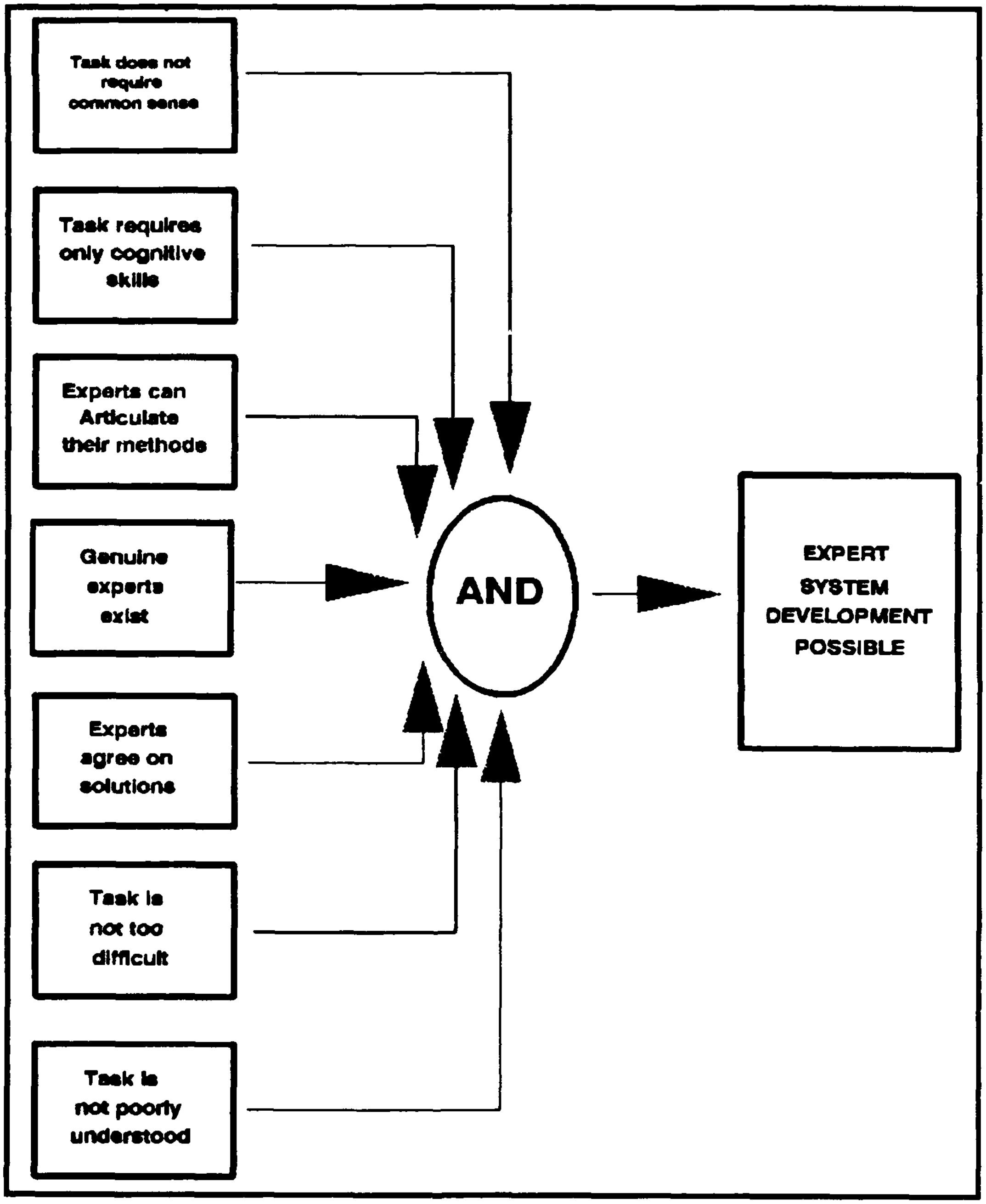

Figure 2.3 Is Expert System Development Possible?

B. When is expert system development justified?

Just because the expert systems approach can be considered for marker making does not mean that the development can be justified. Figure 2.4 illustrates some of the many supportive reasons for advocating the development effort.

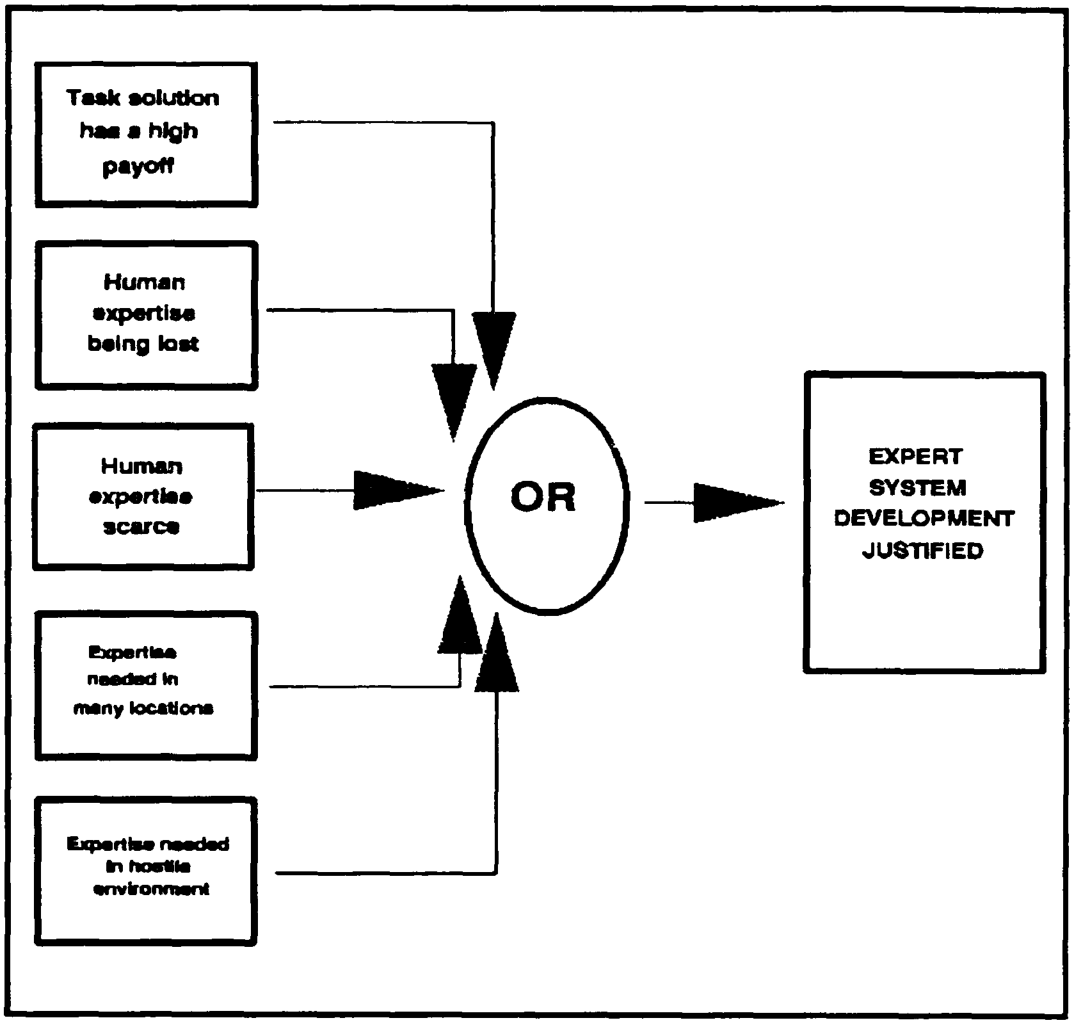

Figure 2.4 Is Expert System Development Justified?

Particularly applicable for the marker making problem are the justifications "human expertise being lost," "human expertise scarce" and "expertise needed in many locations." Certainly human expertise in marker making is a valued asset to an apparel manufacturer; one a company can hardly afford to lose. Yet such situations arise often due to sickness or vacation time or attrition due to the marker maker leaving the job for some reason or another. Training a new person to the skill level of an expert may take years, and certainly many months. With

regard to expertise being needed in many locations, reference is being made to the need to utilize marker information in such areas as costing, planning cuts and work-in-process (WIP) release, and in the actual marker making process itself. The subject will be discussed further in sections 3.4 and 3.5 dealing with economic analysis.

C. When is expert system development appropriate?

The key factors in deciding when expert system development is appropriate are the nature, complexity, and scope of the problem. Figure 2.5 illustrates these key factors and their characteristics.

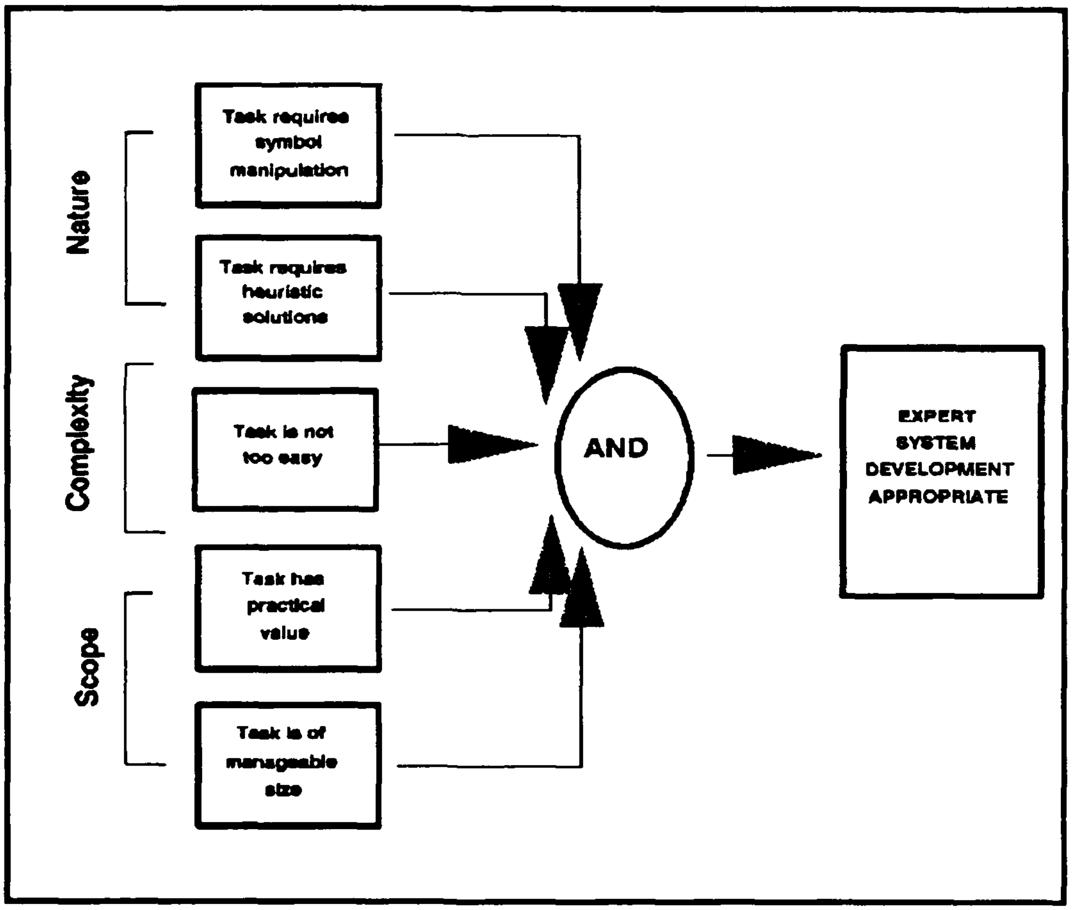

Figure 2.5 Is Expert System Development Appropriate?

Nature. Marker making certainly requires symbol manipulation and heuristic solutions. This means that instead of solving the marker making problem by using sets of equations or performing other mathematical computations, experts use symbols to represent the problem concepts and apply various strategies and rules of thumb to manipulate these concepts.

Selecting a pattern piece, and deciding where to place that piece, and in what orientation is an example of symbolic manipulation. Rules of thumb or heuristics applicable for this example might be "select the piece not yet placed in the marker which has the largest area," and "place the next piece so that it is adjacent to the last piece added to the marker."

Complexity. The problem must not be too easy. If this were so for the marker making problem, a conventional computer program could be designed to solve the problem and current CAD systems would have already incorporated such a conventional solution.

Scope. Finally, the marker making problem certainly has practical value and is of manageable size. The problem is not so broad that relevant issues and constraints cannot be considered simultaneously.

Thus, having confirmed all of the questions posed, it seems that an expert systems approach *will* work for the marker making problem. This does not mean that current computer systems and solution methods should be discarded. A scenario for successful application of expert systems to this task will probably include the following:

1. Apply optimization methods to produce an "automatic marker."

2. Give the solution from step 1 to an expert system for evaluation and improvement processing.

3. Give the improved solution from step 2 to a human expert for further evaluation and improvement processing.

Thus, it seems that developing an expert systems approach to the marker making problem is a viable and promising area for future research.

2.4.2 Neural Nets

Theoretical explanations of the human brain and its thinking processes were first suggested by such philosophers as Plato (cc. 400 B.C.) and Aristotle (cc. 350 B.C.) (see Kohonen, 1988). Analytical neural modeling concepts were first theorized in the 1940s. Since that time, researchers have continued to pursue many areas in this research field. The number of papers on general neural modeling easily numbers in the thousands.

The nature of neural computing. Neural computing is in theory very closely related to the function of the human brain. However, one usually only has in mind the *sensory* and *motor* functions, as well as some kind of "internal processing," loosely called *thinking*. All of these functions are mutually dependent in one way or another, but it may be possible to conceptualize some of them in idealized forms.

Neural computing is a divergence from traditional Artificial Intelligence techniques, in that it involves the use of massive parallelism, so that computing capacity is increased by orders of magnitude. The question remains as to *what* to compute. One new dimension of visible computation very difficult to reach by digital computers is to take into account all the high-order statistical relationships in stochastic data. The best "intelligent" machines developed so far can deal only with data in discrete form, whereas the biological brain can deal with "stochastic signals" (see Kohonen, 1988).

Kohonen (1988) defines artificial neural networks as follows:

> " 'Artificial Neural Networks' are massively parallel interconnected networks of simple (usually adaptive) elements and their hierarchical organizations which are intended to interact with the object of the real world in the same way as *biological nervous systems do.*"

He goes on to say that such "neural computers" do not execute typical machine instructions of digital computers. In principle, the basic operation performed by every processing element is an analog operation, or transformation of its input signals. Lippman (1987) describes the operation of a neural computer as exploring many competing hypotheses simultaneously, using massively parallel networks composed of many computational elements connected by links having variable weights.

Biological neural networks are vast in size. It is estimated that the number of neurons is on the order of 10^{11}, and the number of their interconnections is even higher, maybe up to the order of 10^{15}. Certain features of this biological neural network are inherited, and a rough allocation of the resources and main communication paths are formed according to a genetic pattern. However, the content of memory (essentially the programming of this network) must be obtained postnatally. Programming of the network means that the structures of the interconnections between cells and that the signal transmittances of these interconnections are changed.

What the biological neural networks are not.

A clear distinction between neural and digital computers is presented in order to provide a better understanding of the real potential of neural computing. The following assertions are given by Kohonen (1988):

1) The biological systems do not apply principles of digital or logic circuits. Accordingly, the brain must be an analog computer.

2) Neither the neurons nor the synapses are bistable memory elements.

3) No machine instructions or control codes occur in neural computing.

4) The brain circuits do not implement recursive computation, and are thus not algorithmic.

5) Even on the highest level, the nature of information processing is different in the brain and in digital computers.

Applications of neural computers.

Lippman (1987) states that the greatest potential for neural network models is in areas such as speech and image recognition where many hypotheses are pursued in parallel, high computations rates are required, and the current best systems are far from equaling human performance. Figure 2.6 illustrates the types of patterns that can "recognized" by the application of various neural network models.

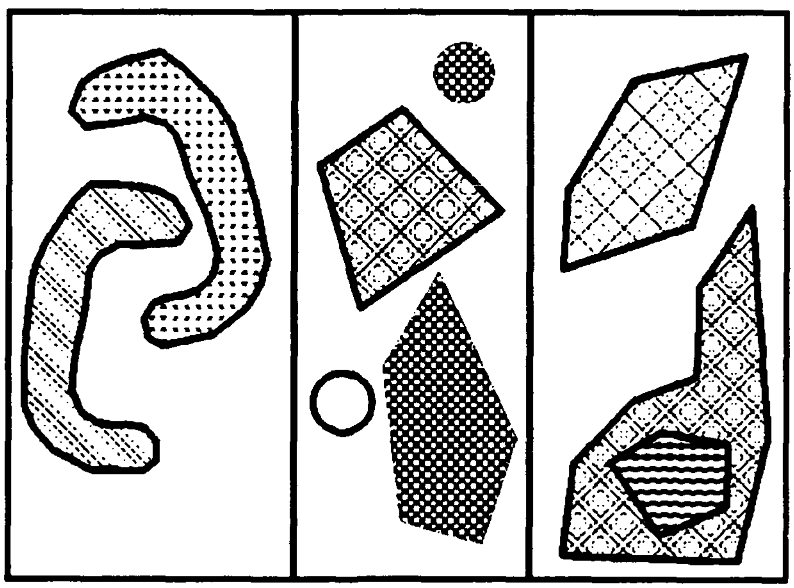

Figure 2.6 Pattern Recognition by Neural Networks

The term pattern recognition was introduced in the early 1960s and originally meant detection of simple forms such as handwritten characters, weather maps, and speech spectra. A more ambitious objective is to imitate the functions of the biological sensory systems in their most complete forms. Because sensory perception is always closely associated with global cognitive processes, it is not enough to imitate the sensory system; rather, one must replicate the whole brain with all its thinking capabilities, and refine the recognition accuracy by high-level learning (see Kohonen, 1988).

Kohonen (1988) concurs on the important application areas for neural computing and expands the ideas even further: pattern recognition in areas such as remote sensing, medical image analysis, industrial computer vision, and input devices for computers. More concrete tasks for which hardware technology has been developed include segmentation and classification of regions from images, recognition of handwritten characters and text, recognition of speech, and processing (especially restoration) of noisy pictures. More difficult areas of application include image analysis (referring to different thematic levels of abstraction, such as monitoring of land use on the basis of satellite pictures), image understanding (interpretation of scenes), and speech understanding (parsing and interpretation of spoken sentences).

<u>Are neural networks a good approach to the marker making problem?</u>

There is both a positive and a negative answer to this question. In negative response, the technology for implementing such techniques is still not widely available. This makes research resources limited and impedes technology transfer. In addition, it is not clear that the marker making problem is truly a pattern recognition problem. It may fall more in the category of pattern creation as opposed to pattern recognition. These "negatives" may not be strong enough arguments against the application of neural networks to the marker making problem to state that this avenue of research should indisputably not be explored. It certainly holds promise for taking advantage of the spatial characteristics of the marker making problem. This type problem is typically handled poorly by digital computers, primarily because there are no "algorithms" for pattern recognition and other sensory techniques required for the solution of the problem. Another direction might be to design an optimization algorithm for parallel processing which could solve the marker making problem to mathematical optimality. If this turns out to be a feasible approach, the entire marker making process could be completely automated. The concept of neural networks should never be completely disregarded as a possible technique for

the marker making problem. As this field becomes more fully developed, application of these concepts my become much easier.

3. Economic Analysis

3.1 Introduction

Continued improvement of the marker making process may include an increase in automation. This section assesses the economic feasibility of this step in the development of marker making technology. It is not an assessment of the economic effect of replacing a manual marker making system with an automated one, but rather, increasing the level of automation. As such, it is concerned with marginal changes in productivity of an already highly productive system.

Economic feasibility rests upon the balance between costs and benefits of pursing an alternative versus not pursuing it. It has been found that this balance is critically dependent upon firm-specific factors for increased marker making automation. Each firm, therefore, must evaluate the costs and benefits to its operation in its decision to invest in increased automation. The assessment presented here seeks to establish the parameters of this decision and, in general, the conditions under which adoption would be advised.

The dominant traditional method of assessing economic feasibility in an apparel manufacturing environment is to divide the capital costs of the potential acquisition by the estimated annual labor savings. This is called the payback period, and paybacks of two years or less are considered most desirable. Recent surveys of apparel executives indicate a growing acceptance of other factors both in determining the maximum acceptable payback period, and in support of non-payback decision criteria. This assessment goes beyond the traditional in that it considers a comprehensive set of factors relating both to the technical qualities of the advancement (and its interactions with other production areas) and the relationship this advancement has to the other business areas in addition to the traditional, quantitative financial evaluations.

This presentation is divided into six subsections. The first establishes the framework in which the analysis is conducted including the key assumptions used in the subsequent analyses. The next three sections (3.3 through 3.5) assess various dimensions of the impact increased marker making automation is likely to have on apparel firms. These include the financial impacts, the interaction with related production areas, and the strategic factors (including marketing strategy) involved in the decision to adopt the improvements. The last section summarizes the results and provides the overall conclusions of the analysis.

3.2 Analytical Approach

Economic feasibility of increasing marker making automation could be considered from several perspectives. From the point of view of the marker making equipment manufacturer, investment in software development would be viable if the market were strong enough to provide a high enough price on enough volume to recoup development costs plus compensation for risks. Market strength, in turn, would reflect the sum of the value each individual apparel firm places on the product. Because the value of the increased automation at the firm level forms the basis for market viability, this is the perspective taken in this assessment.

The methods used to assess the value the software would represent to a firm in a given situation are currently expanding to include both quantitative and qualitative dimensions. It has been expressed in many recent analyses (Hayes, 1982; Meredith, 1986, and Riall, 1988 and 1990) that the nature of increased automation poses great difficulties to the quantification of costs and benefits, and marker making is no exception. Where a benefit (or cost) cannot be quantified, the traditional practice would be to exclude it as being too speculative. The traditional practice therefore excludes many of the benefits offered (and costs required) by the new technology. The approach used in this analysis attempts to improve upon the traditional methods in several ways. First, the quantification of benefits extends beyond those traditionally estimated to include, for example, the costs of employee turnover. Second, the interaction of the marker making function with other production areas is assessed qualitatively. And third, the strategic implications are assessed. An important implication of this approach is that even though the quantitative assessment of the benefits of increased marker making automation is expanded beyond the traditional sphere, many benefits remain nonquantifiable, so that the quantitative portion of this analysis should therefore be considered a lower bound of the value the software would be likely to represent.

The qualitative factors, while certainly affecting the profitability of the firm, cannot be reasonably quantified in this analysis for a number of reasons. First, they may be probabilistic in nature with no knowledge existing on the shape of the distribution. Second, the variance among firms may be so large that attempting quantification for a general case would be meaningless. Third, they may depend upon future events that cannot be predicted. The approach taken is to identify the factors important to the feasibility of increased marker making automation and to specify the conditions that would affect the level of benefits or costs accruing to the firm. Throughout the assessment, factors which were investigated but found unlikely to be significant will also be presented.

3.3 Financial Analysis

The wide variety of situations in which automated marker making would be applied in the apparel industry complicates the task of assessing financial feasibility. The approach taken here is to develop illustrative scenarios which are reasonable, though not necessarily accurate, as explained in the previous section. The examples are revealing, however, in depicting the variables important to the decision and providing boundaries the financial impacts are likely to have on a firm adopting the increased marker making automation.

3.3.1 Cost and Benefit Categories Quantified

The costs of adopting automated marker making comprises initial costs and recurring costs. The initial costs consist of the purchase price of the software, but do not include any hardware. This follows from the assumption that this is an upgrade of an existing computerized marker making system already containing the necessary hardware. Other initial costs include the training of the operators and supervisors overseeing the operation of the marker making function.

The benefits are the reduced labor required in making the required markers and in the reduced training time required to bring an inexperienced worker up the learning curve to a minimally functional level.

Factors considered but rejected as likely to be insignificant are the disruption to the operation of the plant and increased fabric wastage as the operators move up the learning curve. Disruption effects are likely to be minimal because the more automated versions would not be radically different from current practices. Similarly, companies upgrading will usually already have many markers in electronic storage that serve as standards against which the new software can be evaluated during the implementation. The new markers would have to be at least as efficient as those in storage or they would not be used.

Throughout the financial analysis, costs and benefits are developed as comparisons of (1) the situation which would exist with the automated software, with (2) the situation which would exist without the software.

3.3.2 Analytical Scenarios

The three scenarios developed to examine the value of more highly automated marker making depict a wide range to reflect the great variety found in the apparel industry.

The first scenario, labeled "Small Company" is characterized by having only one marker maker, who, because of the general stability of the styles manufactured, uses a relatively small percentage of time actually developing new markers. The remainder of time is spent plotting stored markers and coordinating with the cut-order planning and the cutting functions. The marker making function has been performed by the same person for many years, i.e., the turnover for the position is almost nonexistent, but should the marker maker decide to leave the firm, there would be no readily available replacement. In the past, when the marker maker was sick, the owner had to step in to fill the gap, as there is no one else familiar with the equipment or the data files. Losing the existing marker maker would therefore require the owner to take up the slack while a new employee was found and trained. Finding a replacement is made doubly hard by the generally low wages paid by the small company and its limited fringe benefits.

At the other end of the spectrum is "Large Company", which has three marker makers working full-time on preparing new markers because of the high rate of new style creation. These workers command high salaries and generous fringe benefits while, paradoxically, turning over their jobs on the average of one position per year.

Between these two firms is "Medium Company", employing two marker makers each working about half-time on making new markers. Their salaries are adequate, but not exorbitant; their fringe benefits are reasonable and their turnover is low, with a new hire every five years.

Table 3.1. Summary of Financial Analysis for Three Scenarios

	Small	Medium	Large
Marker Maker Salary	$12,000	$18,000	$25,000
Fringe Benefits	10%	15%	20%
Number of Marker Makers	1	2	3
Time Making Markers	25%	50%	100%

3.3.3 Base Case Analysis

Because the development costs, market, and price for the software are not reasonably predictable within the scope of this research, the central question posed by the financial analysis is what is the maximum price each of these firms would pay?. This is calculated by taking the present value of the net cash flows resulting from adopting this software, as compared to not adopting it. The time horizon taken for this decision is 10 years, and the discount rate is

assumed to be 12 percent. Table 3.1 provides a summary of each of the three scenarios as a base case. It is assumed in the base case that the increased marker maker automation cuts the time required to make a new marker so that produstivity is increased by 50 percent.

The initial training is not expected to be highly demanding because of the familiarity with computerized marker making systems by existing personnel. A maximum of two days would be a reasonable expectation for training initially. A period of two weeks of diminished productivity would be reasonable to assume while the operator moves up the learning curve. A typical learning curve depicting this relationship between time and productivity is given in figure 3.1.

A key point in assessing the costs of training is opportunity cost of the reduced productivity during the learning process. If the learning curve is similar to that depicted in figure 3.1 and the productivity with the new software is compared with not having the software, then an operator could be expected to achieve the old level of productivity in the first week and reach maximum productivity (150 percent of the old level) after the second. What, then, is the cost of the lost production in the first week, and what is the value of the higher production achieved in the second week, and all weeks thereafter?

It is typically assumed in traditional financial analysis that labor is infinitely flexible, i.e., that any decreases to labor productivity are compensated for by increasing labor costs proportionally, and any increases to labor productivity result in lower labor requirements.

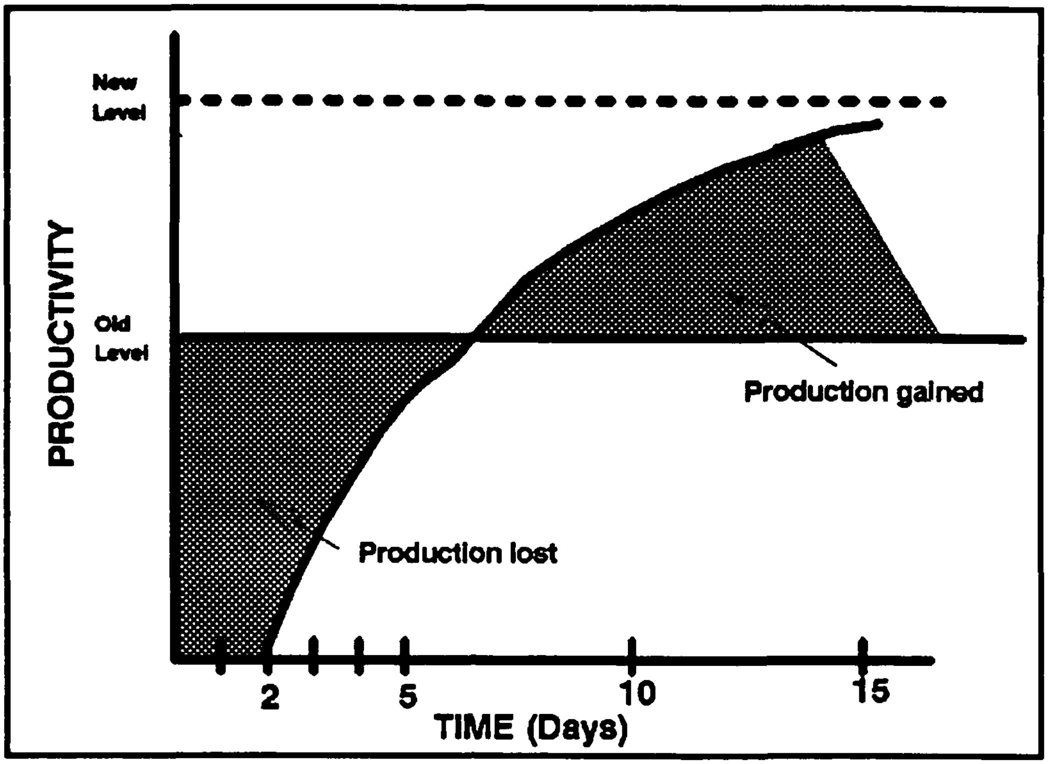

FIGURE 3.1
Hypothetical Learning Curve for Implementing
More Highly Automated Software for Marker Making

Hiring and firing to meet these decreases and increases in productivity are not, however, realistic or practical alternatives. What, then is a better alternative way to view these changes in productivity?

As discussed in later sections, markers contain information useful to other areas of the firm which, with increased access, will likely become more widely used. This is, in effect, an increase in the internal demand for marker making within the firm. It is assumed in this analysis that the increase in demand for markers will begin to increase in the first year following the two-week implementation period and will match the higher productivity provided by the new software at the beginning of the second year of implementation. Overtime would be required to maintain the marker production at the pre-automation increase levels during implementation, and the average value of either the alternative uses for the labor (freed up by lowered time required to meet the demand for markers), or the additional markers made, would be half of current values, which are fully realized in the second year.

Applying these concepts to each of the three scenarios used in the financial analysis is accomplished as follows. For Small Company, the slack in the two days of training and the first week of implementation can only be taken up by the owner. While the marker maker could also work some overtime (at a lower salary) to make up the production, the owner must, because of his position as backup, also learn the software during this period. The opportunity cost of the owner's time is assumed to be $75,000 per year. The owner would be required to perform the marker making function for the two days of the marker maker's training plus the equivalent of 2.5 days of marker making time while the trainee gets up the learning curve. Even though the marker making function requires only 25 percent of the employees time, it is assumed that the owner must put in the full 4.5 days to learn the new system. The total cost, using a $75,000 annual (260 days) salary with fringe benefits at 10 percent of salary, would be $1,428.

For Medium Company, the two marker makers share the overtime burden for the first implementation, which is reduced (because of the increased productivity) for the training of the second operator. Similarly, Large Company spreads its overtime requirements over its three operators with the production lost during the third operator's training completely covered by the increased productivity of the first two. For both Medium and Large companies, the total overtime burden is 5.5 days for training and implementation with salary costs at a time-and-one-half overtime premium. For Medium Company, this would cost $537, and for Large Company $778, because of the differences in salary and fringe benefits.

The productivity of the marker makers doubles (i.e., the time required to make a given marker drops by 50 percent), under the base case, following the implementation for all companies. The companies now have two options. First, they can reduce their marker making labor by 50 percent, which is the traditional assumption. Second, they can use the additional markers either for increasing production, changing styles more rapidly, or use them as information in their pricing and fabric ordering. If it is assumed that the value of the extra marker production, in whatever use they are put, is equal to its average cost under the new system, and the existing markers were equal to their cost under the old system, then the marginal production would be worth 50 percent of the existing labor costs, i.e., a percentage coincidentally equivalent to the traditional assumption. If it is further assumed that the first year of increased productivity cannot be absorbed completely by the firm, then the first year value would be less than subsequent years. If the absorption of additional markers moves from zero to 100 percent over the course of the first year, then a 50 percent average value would be reasonable. The resulting projected cash flows for each of the three scenarios, and the calculated present values are given in Table 3.2.

Table 3.2. Cash Flows Under Three Scenarios				
	Implementation Costs	Benefits in First Year	Benefits in Years 2-10	Present Value
Small Company	$1,428	$825	$1650	$7,311
Medium Company	$537	$2588	$5175	$26,450
Large Company	$779	$7500	$15000	$77,362

3.3.4 Assessment of Employee Turnover Impacts

An important benefit of more highly automated marker making software is the lower skill levels required of new operators when a position turns over. Again, adopting the with versus without perspective provides the basis for estimating the financial impacts of turnover. Without the increased automation, it has been reported that a person with apparel experience could begin making adequate markers in one to three weeks. It is assumed that two weeks are required to reach the 50 percent productivity level on the learning curve. Achieving the same level of competency without apparel experience may require as much as three to six months (Rivoli Mills, 1990). A much more conservative figure of 1.5 months is used in this analysis.

Because there is no experience base for implementing this now nonexistent software, its impacts on the cost of turnover must necessarily be speculative. It is likely, however, that with the increased automation, the time required for either someone with apparel experience *or* computer experience would be about the same. Speculating further, it is reasonable that a training period of about one week would enable an experienced person to make adequate markers. An additional week of training would be required for someone with no computer experience. For the purposes of this exercise, "producing adequate markers" is defined as having a 50 percent productivity level on the learning curve, as depicted in Figure 3.2. Productivity high enough to subsequently meet the needs of the company in its normal operation is assumed to be reached in twice the time required to reach 50 percent productivity.

The cost of turnover is estimated on the basis of what the company must do to make up the production lost during training of the new hire. For Small Company, the only alternative is for the owner to fill in. Medium and Large companies can pay overtime to their other operators. Table 3.5 provides the cost estimates per turnover under the two alternative experience levels of the new hires, i.e., those having apparel experience and those not having apparel experience. It is significant to note that with the increased automation, 'experience' may also be in computer operation, which is a large and growing population in contrast with apparel experience, which is a small and shrinking population. The probability of finding someone with experience is

therefore much greater with the increased automation. This is an important consideration but one which cannot be quantitatively assessed without some knowledge of the relevant probability distributions.

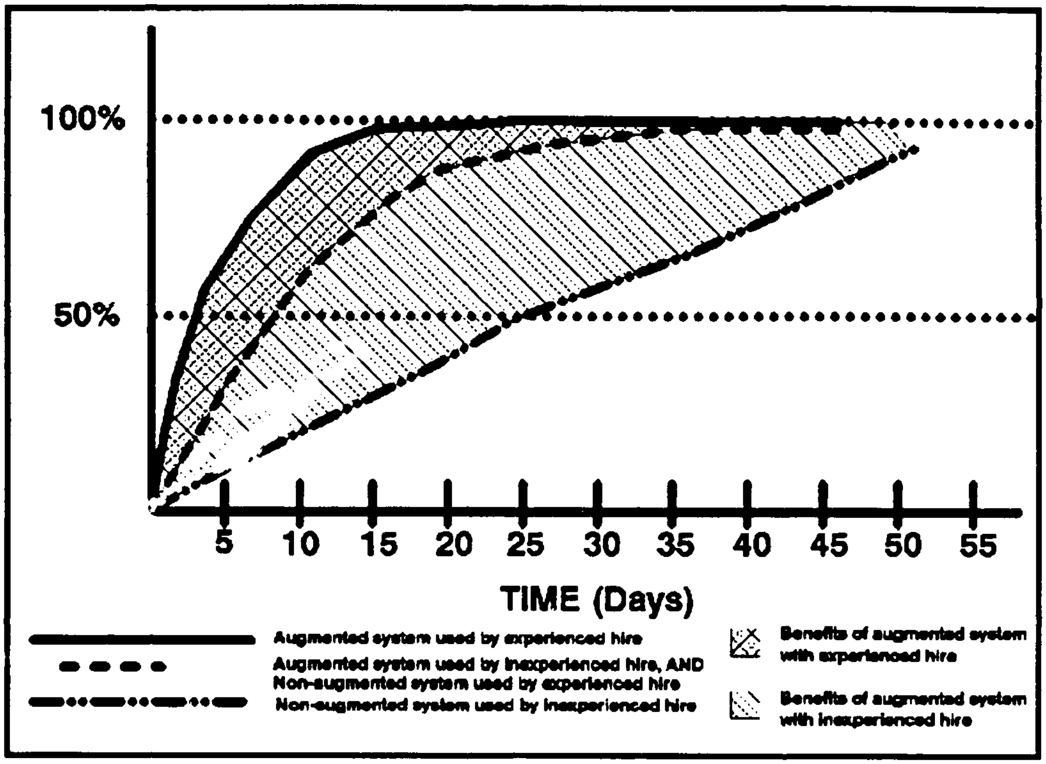

FIGURE 3.2
Hypothetical Learning Curves With and Without
More Highly Automated Software

TABLE 3.3 Impact of Turnover: Training Time Required for 50% Productivity Level (person days)		
	New Hire Available:	
	With Experience	Without Experience
With Increased Automation	5	10
Without Increased Automation	10	32.5

TABLE 3.4 Impact of Turnover: Overtime Required for Meeting Production (person days)		
	New Hire Available:	
	With Experience	Without Experience
With Increased Automation	6.25	12.5
Without Increased Automation	12.5	40.62
Net Benefit of Automation	6.25	28.12

TABLE 3.5 Cost to Firms per Turnover:		
	New Hire Available:	
	With Experience	Without Experience
Small Company	$1,983	$8,924
Medium Company	$746	$3,358
Large Company	$1,082	$4,868

Not only are there differences among the three companies for each turnover, but differences in their turnover patterns as well. Medium Company is assumed to turnover one position every five years on average and Large Company turns over a position every year. Small Company, while not experiencing any turnover in the single position, is nevertheless subject to the possibility of turnover so is assumed to experience a turnover in the first year to illustrate its impact on the present value of increased automation. The resulting present values for each of the three firms is given in Table 3.6.

TABLE 3.6 Present Values of Increased Automation Including Hypothesized Turnover		
	New Hire Available:	
	With Experience	Without Experience
Small Company	$9,082	$15,279
Medium Company	$27,007	$29,330
Large Company	$83,319	$104,711

These data demonstrate the high potential values of increasing the level of automation in marker making. The results should be considered highly speculative but are based upon reasonable expectations of the capabilities of the software and benefits to apparel companies.

3.4 Production Qualitative Impacts

Marker making's role within the firm is a complex one, if one is to minimize costs and maximize benefits. The primary output of the marker making function, i.e., a piece of paper showing the parts to be cut and/or a set of computer instructions for the cutter, represents a solution to a difficult problem involving several functional areas within the firm. The additional capabilities are both near-term and speculative.

3.4.1 Marker Making

The benefits associated with decreasing the time to make a marker, reduced training time, and easier hiring (as discussed in the financial analysis) are the primary benefits to the production process. Increased automation would also allow for operation of the system in the absence of an operator, such as overnight. The operator could queue-up markers when leaving for the day to be ready when the operator returns the next morning. While it is unlikely that these markers would not require review, they would be good starting points for the final markers. Such a capability would increase the utilization of the system with potential savings in hardware and labor costs. It should be noted, however, that a multitasking operating system could allow essentially the same benefit during operating hours.

The quality of the markers now being produced with existing software is quite high, implying a low probability for significant improvement in fabric utilization. The exception to this is found in the practice (identified in the course of this research but used by an unknown number of firms) of using stock markers composed of a only one or two sizes. Research reported in Apparel Manufacturer (1989) indicated that three-size markers improved utilization by as much as 1.7 percent. Increased automation would encourage the consideration of more complex, three-size markers and make them easier to produce.

3.4.2 Planning

An important objective of the marker making process is the minimization of fabric waste. This is accomplished by packing the odd-shaped pieces as tightly as possible. But before this can be done, it must be decided which pieces are to be cut. This is determined by the cut order plan which has its own set of objectives, primarily minimizing the number of cuts that are made.

Currently, cut order planning is generally done separately from marker making, although indications are that the cut order planning process could benefit from the information developed

in marker making. A different mix of sizes, for example, could improve fabric utilization without increasing the total number of cuts required. Spreading and cutting costs may, in the future, be incorporated into an algorithm along with fabric costs to determine the optimum cut order plan. One of the difficulties in accomplishing this, however, is the time required to test the impact on fabric utilization under alternative cut order plans. A more automated marker making system, requiring less time, may allow the marker making and cut order planning functions to become more fully integrated. The benefits of this integration would be more efficient spreading, improved fabric utilization due to the improved spread, and possibly increased cutting efficiency.

The information from the marker making process provides the quantity of fabric required to complete an order, and the length of the spread. This is important in the estimation of costs and in ordering fabric.

3.4.3 Design

Automated marker making would improve a firm's ability to design for manufacturability. Having the capability to determine what the markers would look like might enable a designer to make minor changes that can have major impacts in the complexity of assembly, fabric utilization, quality of the product, and cost. To realize these benefits, however, additional investments in implementing the design for manufacturability concept may have to be made. It can be said, however, that increased automation in the marker making process supports this concept in an important way.

It should be noted that existing marker making systems could be used by the designers for essentially the same purpose. They would require, however, considerable training and experience in marker making or would have to be performed by the existing marker making personnel. Even the more automated system would benefit from extensive marker making experience before design changes are implemented based upon the output of the automated system. It may be that the additional marker maker operator time made available by increased automation could be used to supplement the design function yielding significant material savings.

These capabilities may be important to firms without design departments. One contractor interviewed during this study has found the existing system helpful in developing recommendations to his customers on design changes they could make, thereby improving his customer relations.

3.5 Strategic Factors

Apparel firms are increasingly concerned with the strategic implications of the technology alternatives confronting them. Dramatic changes in the way retailers manage their stock places premiums on the ability to respond quickly to orders. Competition from offshore facilities continues to grow And labor markets are projected to become tighter in future years. This analysis assesses the impact of increasing the level of automation in marker making on strategic factors in the areas of customer service, risk, and how this technology affects future options.

3.5.1 Customer Service

Increased automation in marker making would provide varying levels of additional customer service capabilities, depending upon the market serviced by the company. A contractor who, in the past, has been supplied the markers to use in its cut-and-sew operations may now find it is increasingly called upon to produce the markers from designs. One contractor interviewed in the course of this study is not only producing more of the markers used in his operation, but is also making design suggestions to customers to improve the quality of their products, or to reduce costs. The marker making function is also used in the cost estimation process, enabling very accurate estimates for wide varieties of products to be costed in minimal time. Increasing marker making automation would reduce the time required to provide this information and, perhaps more important, would make the information more accessible. Presently, only expert marker makers, working in the cutting room, can provide the information needed. With increased automation, the salespeople in the business office could, with minimal training, also provide this information. It is even conceivable that the marker making function could be moved from the cutting room to the business office.

Manufacturing flexibility and speed of response are two key strategic factors to success in apparel manufacturing. However, as the existing systems operated at a lower level of automation are quite fast, it is unlikely that increased automation would provide more than one or two hours of increased speed of response, and the increased flexibility would be minimal considering the overall production process.

3.5.2 Impact on Risk

Making a purchase of new software entails an intrinsic risk to the apparel firm. Obviously, the purchase price may be forfeit if the application is unacceptable, but more important are the unknowns. Although software engineers are becoming more adept at meshing

software to applications, there remains the potential for errors that could send the cutter careening across the spread, or more likely, large numbers of data files to be destroyed or otherwise made unusable. Given the incremental nature of this advance, however, these scenarios are unlikely and can be safeguarded against. More important are the potential reductions to risk represented by increasing marker making automation.

The greatest risks affected by increasing marker making automation relate to employee turnover. Increased automation, in this instance, leads to a deskilling of the job. The risk thus reduced is that of finding replacements within a reasonable time. The value of this is accentuated for a small company which may have only one person to produce the markers. A loss of this function could seriously jeopardize the ability of the company to meet its delivery schedules. Increasing the level of automation enables markers to be made with lower skills while a replacement is being found and trained. The markers made with the automatic mode may not be optimal in terms of fabric utilization, but they would certainly be superior to those made without the automation by an inexperienced operator.

Another risk reduced is the increased flexibility to meet unknown future challenges and opportunities, as discussed in the following section.

3.5.3 Preparing for the Future

Computer applications are growing in the apparel industry, as they are all industries. Integrating the information from disparate areas within the firm is one of the key advantages offered by increasing computerization. In apparel, the business areas of marketing, cost estimation, customer service, and strategic planning are becoming more closely integrated with the production floor. Automated marker making makes the information contained in the marker more accessible to these other areas thus providing a potential competitive advantage. Computer integrated manufacturing would be enhanced with automated marker making.

There are several problems currently under study in the apparel industry which may have solutions aided by more automated marker making. For example, computer-aided design is not yet to the point where three-dimensional garments can be dissected automatically into the two-dimensional pattern pieces used in the marker. It is likely, however, that this capability will be developed in the future. If a designer has a high-quality automated marker maker available, then it would be possible to develop garment costs. The impact of alternative designs on the cost could then be explored, potentially leading to more efficient designs. While this design

capability does not presently exist, increased marker making automation would prepare the firm for it, and may be a key component in realizing the greatest benefits from it.

3.6 Conclusions

Assessing the economic viability of increasing marker making automation is made difficult without the specific performance characteristics of the software or its costs. It is possible, and hopefully informative, to develop scenarios that explore the financial advantages of such an advance, and to speculate upon its intangible benefits. It has been shown that under reasonable operating assumptions firms in a wide variety of circumstances could benefit from the increased automation. The quantitative benefits are dominated by the reduced time required to produce the markers (or, conversely, the value of the additional markers made possible by the increased productivity), and the reduced training and steeper learning curves resulting from the deskilled task. This is especially advantageous for a small firm with all of its marker making expertise residing in one person. Such a firm would suffer considerably reduced disruption and costs if marker making could be made more automated in the event of the loss of the marker maker. All firms would benefit from the decreased training requirements and the expanded employee pool resulting from a deskilled marker making function.

Increased marker making automation would also offer customer service and strategic advantages. Markers contain valuable information useful to customers, in both cost estimation and garment design. A more automated marker making function would increase the accessibility of this information and the level of integration of the various areas of the firm that could use this information. As firms move toward computer integrated manufacturing and advances are made in areas such as computer-aided design, the value of more automated marker making will likely increase.

4. Conclusions and Recommendations

In drawing conclusions and making recommendations from this study, there are three questions which should be addressed:

1. Can current marker making systems produce markers automatically?
2. Is it technically feasible to automate the marker making process?
3. Given the technical feasibility of automating the marker making process, can the development effort be economically justified?

This study was not needed in order to answer the first question. Vendors have claimed for some time they can provide software that has an "automatic" mode. In fact, this is true. Some of the current systems do have the ability to produce a marker with no intervention from the operator. The downside of this issue is that no system yet has consistently performed better than a human marker maker. However, this does not mean that automation with better performance is not possible. So, this leads to the second question.

In answer to the second question, this study has shown that it is technically feasible to automate the marker making process. The technology exists, and in fact is being applied in some existing systems, for automation with an "optimization" approach. While the current methods are not optimal, the heuristics which have been implemented are very similar in nature to some very simple ones discussed in the literature for solving the cutting stock problem. Optimization can be a very valuable tool, and there may be new heuristic approaches, or adaptations of existing methods which could lead to satisfactory techniques for "automatic" marker making. Therefore, even though the literature does not provide immediate answers for finding an "optimal" solution to the marker making problem, further exploration of optimization-based heuristics is likely to advance the ultimate achievement of automatic marker making.

Other approaches to be examined in future research efforts should include expert systems and neural networks. A series of questions was posed and the questions answered affirmatively to confirm the feasibility of using an expert systems approach. This does not mean that current computer systems and solution methods should be discarded, or that no further work should be done in the optimization area. A scenario for successful application of expert systems to this task will probably include the following:

1. Apply optimization methods to produce an "automatic" marker (gardless of quality).

2. Give the solution from step 1 to an expert system for evaluation and improvement processing.

3. Give the improved solution from step 2 to a human expert for further evaluation and improvement processing.

With regard to the application of neural networks to marker making, this field is currently a very popular topic in computer science, but the technology for implementing such techniques is still not widely available. More important, it is not clear that the marker making problem is truly a pattern recognition problem. It may fall more in the category of pattern creation as opposed to pattern recognition. Regardless of the negative aspects of this concept, there is still strong evidence that the application of neural networks to the marker making problem should be explored. It certainly holds promise for taking advantage of the spatial characteristics of the marker making problem. This type problem is typically handled poorly by digital computers, primarily because there are no "algorithms" for pattern recognition and other sensory techniques required for the solution of the problem. Another direction might be to design an optimization algorithm for parallel processing which could solve the marker making problem to mathematical optimality. If this should prove to be a feasible approach, the entire marker making process could be completely automated. The concept of neural networks should not be disregarded as a possible technique for the marker making problem.

This leaves only the third question: can further work on automatic marker making systems be economically justified? The participating vendors all seem confident that improved systems are just around the corner and that improvements can be well-justified by using automatic markers in the costing of a garment, by deskilling the process so training can be affected in short periods of time, and by the faster turnaround time of an automated process. All users agreed that automatic marking would be a great benefit, but they were not actually using the "automatic" modes currently available. General comments about the usefulness of such an automated system include those things that have already been mentioned: costing of garments, deskilling the task so that a company is not so dependent on the presence of a marker maker, and improved processing time.

It has been shown that under reasonable operating assumptions firms in a wide variety of circumstances could benefit from the increased automation. The quantitative benefits are dominated by the reduced time required to produce the markers (or, conversely, the value of the

additional markers made possible by the increased productivity), and the reduced training and steeper learning curves resulting from the deskilled task. All firms would benefit from the decreased training requirements and the expanded employee pool resulting from a deskilled marker making function.

Increased marker making automation would also offer customer service and strategic advantages. Markers contain valuable information useful to customers, in both cost estimation, and garment design. A more automated marker making function would increase the accessibility of this information and the level of integration of the various areas of the firm that could use this information. As firms move toward computer integrated manufacturing and advances are made in areas such as computer-aided design, the value of more automated marker making will likely increase.

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Appendix

VENDOR SURVEY

1a. I'm going to read you a list of hardware. For each piece, please tell me if it is necessary in order to run your marker making package.

1b. What is the approximated unit cost for the __________ needed to run your package?

1c. If a customer purchases your marker making package, are they required to purchase hardware from you? From the list of hardware I just read, which pieces are they required to purchase?
(RE-READ LIST IF NECESSARY)

Hardware	1a Necessary to run?	1b Cost	1c Required Purchase?
Scanner	______	_______	______
Digitizer	______	_______	______
Plotter	______	_______	______
Laser Printer	______	_______	______
Computer (please give type)	______	_______	______
Other:____________________	______	_______	______

2a. Now I'd like to talk about the training needed in order to run your marker-making package. Approximately how many classroom hours are necessary?

_________ Hours

2b. What topics are covered in the training?

2c. Does the training include any hands-on exercises? Approximately h w much time is involved?

Yes - 1 No - 2

2d. What is the approximate cost for training an operator in the use of your system?

_________________________ dollars/person

3. Does your software require any prerequisite skills that are not covered during training sessions?

Yes - 1 No - 2

4a. Does your system allow for ____________?

4b. Which of these constraints can the operator override?

	Allow?	Override?	
a.	______	______	Nap constraints?
b.	______	______	Tilt constraints?
c.	______	______	Color matching constraints?
d.	______	______	Flip constraints?
e.	______	______	Pattern matching constraints?
f.		Other constraints? (Specify)	

5. Does your software have the ability to offer the operator suggestions as to the placement of pattern pieces? (IF YES) Please describe the features that make it easier for the operator to do her job.

6a. Does your software offer an "automatic" mode of operation, where a marker can be generated without operator intervention?

Yes - 1 No - 2

6b. (IF YES) Does the automatic mode use an algorithmic approach, a heuristic approach, or an expert system approach?

______ algorithmic

______ heuristic

______ expert system

6c. Is the quality (in terms of fabric utilization) of the automatically produced marker better, worse, or about the same as markers produced with operator intervention?

Better - 1 Worse - 2 Same - 3

7. What is the range of fabric utilization of an operator produced marker using your system? (IF SYSTEM HAS AUTOMATIC MODE) What is the range of fabric utilization for an automatically produced marker?

Operator produced: From _____% to _____%

Automatically produced: From _____% to _____%

8a. What is the average time for an operator to produce a marker with your system? (IF SYSTEM HAS AUTOMATIC MODE) What is the average time required to produce a marker in the automatic mode?

Operator-produced time ____________________

Automatic time ____________________

8b. What determines how much time is required?

9. Is there more than one version of your package available commercially? (IF YES) Please describe the features of the least expensive or least complicated package (including price). Please describe the next most complicated or expensive package. (REPEAT AS NECESSARY)

10. We would like to understand your system as thoroughly as possible. Please tell me about any other features that were not covered by the questions I've already asked which you feel are pertinent in helping us to understand your system.

11a. Does your company plan to implement any new or additional "automatic" features in your marker making system within the next year? (IF YES) please describe these features.

11b. If a full upgrade for existing systems is available, what do you estimate will be the price of your package, when these features are included? How much do you anticipate you will charge existing users for an upgrade?

Full package price $____________

Upgrade price $____________

12. What other improvements or added features are you planning for your system, within the next year?

13. What improvements or added features would you like to implement in your system but have no current plans for doing so?

14. To help us understand your system better, it would be helpful to see it in use. Could you give me the names of some users of your system who who have cut and sew plants in the Atlanta area?

VENDOR RESPONSES TO SURVEY

Company B

	1a Necessary to run	1b Cost	1c Purchase Required
Scanner	No	1	Yes
Digitizer	Yes 2		Yes
Plotter	Yes		Yes
Laser Printer	Yes 3		Yes
Computer	Yes 4		Yes

Omnicomp Controller (graphics display mouse or pointing device).

1. Turn-key system with hardware, software, training, support: Min system $50-55k. Expansions different.
2. If no pattern design front-end.
3. Not required.
4. AT okay.

Company C

	1a Necessary to run	1b Cost	1c Purchase Required
Scanner	No	1	No
Digitizer	Yes		No
Plotter 2	Yes		No
Laser Printer	No		No
Computer 3	Yes		No
4	Yes		No

1. See fax sheets.
2. Or Cutter.
3. IBM clone with hard disk and floppy, at least 16 mHz, at least 286-based.
4. Graphics Display (supports Windows) Mouse or pointing device, at least VGA, at least 16" monitor.

Company A

	1a Necessary to run	1b Cost	1c Purchase Required
Scanner	No		1
Digitizer	Yes 3		2
Plotter	Yes 4		
Laser Printer	Yes 5		
Computer 6	Yes		
7	Yes		

1. Complete System $45-50 K
2. Workstation (-plotter, -digitizer range $20-25K)
3. For input of existing pattern
4. For outputs
5. For standard reports
6. 16 mHz 386 based, but portable to others (no 286)
7. Graphics Display (HD 15", 19", beyond VGA. Monochromatic screen management workstation screen.

2 a.
Company B
One week in Dallas, follow-up on site (one week). 6-8 workstations.

Company C
Classroom at Company C, $300/day/person 3 1-day courses ($750 for all three days).
$700/day & expenses for training on-site (unlimited number of persons to be trained). System comes with tutorial: 75% of customers train themselves. 90 day warranty, free telephone support: Annual fee of $300 for phone support (@ $1/min) & free upgrades.

Company A
Video basic. Classroom-on site 32 hours (4 days) or at headquarters. PDS users - video instruction 32 hours. Other packages(??) of 1 day training and regional seminars

2 b.
Company B
Digitizing
Grading Marker Making
Plotting
DOS operating system

Company C
Day 1: DOS & Windows
Day 2: Input, Grading, Marker Making, Output
Day 3: Hands-On experience (OJT)

Company A
Tailor to individual customer
- setup (??)
- Marker definition
- parameter setting
- manipulating pieces

Don't do "how to" make a marker.

2 c.	Co. B	Co. C	Co. A
	Yes 1		Yes 2

1. Almost all of training
2. For entire training session

2 d.
Company B: 2 week training period: cost of lodging, travel, meals at Dallas facility

Company A: 32 hours equals $1200 - $2000. On site equals $3500 - $4000. The video is free.

3

	Co. B	Co. C	Co. A
	No		Yes 1.

1. Knowledgeable in area they're training in.

Company B
4.

	Allow?	Override?	Constraints
a.	Y	Y	Nap
b.	Y	Y	Tilt
c.	N	n/a	Color Matching 1.
d.	Y	Y	Flip
e.	Y	Y	Pattern Matching

Company C
4.

	Allow?	Override?	Constraints
a.	Y	Y	Nap
b.	Y	Y	Tilt
c.	Y	Y	Color Matching 1.

d.	Y	Y	Flip
e.	Y	Y	Pattern Matching
	Y	Y	Rotation
	Y	Y	Overlap
	Y	Y	Pattern Splitting

1. & Shading

Company A

4.

	Allow?	Override?	Constraints
a.	Y	Y	Nap
b.	Y	Y	Tilt
c.	Y	Y	Color Matching 1.
d.	Y	Y	Flip
e.	Y	Y	Pattern Matching
	Y	Y	Overlap of pieces
	Y	Y	Group pieces
	Y	Y	Splitting pieces

1. & Shading

5. Company B: No
Company C: No
Company A: No

6 a.

Company B: Yes. Basically interactive. Repeat Capability: repeats a placement that operator has already made. OR "Automatic MM" = No operator intervention - can be interrupted.

Company C: No.

Company A: Yes (For most advanced version), No (For simpler version)

6 b.

Company B: Heuristic

Company A: Algorithmic (?) Expert Systems (loosely) Two alternatives. more advanced version ability to teach the system to lay a marker by a certain method.

6 c.

Company B: **Worse**

Company A: Worse (for algorithmic) Better (for "expert system").

7.

Company B: Operator: from 85 to 92%

Automatic: 1 to 2% less (Usually has to be reworked).

8 a.

Company B:

Operator produced time: 2-3 pieces/minute

Automatic time: <1 to 30-60 minutes/200 pieces, or half the operator time or 4-6 pieces/minute

Company C:

High Fashion Industry Goal: Place 2 pieces/minute

Jeans: Place 3-4 pieces/minute

8 b.

Company B:

1. How many pieces in pattern
2. Complexity of the pieces " proportional to the number of digitized parts on the piece.
3. How many sizes in marker.

Company C:

Type of industry

Number of pieces in marker

Amount of freedom allowed (rotation, flip).

Fewer constraints yield less efficient marker and less time

Product Quality

Company A:

1. How well you can utilize the width of the fabric
2. Similarity of pieces with respect to lines and curves (complexity).
3. Size of pieces (small pieces are great to fill "holes.")

9.

Company B: No.

Company C: No

Company A:

More advanced version: Major focus on marker making, still has some more sophisticated features not included in simpler version.

Simpler version: focus on use of system throughout process of apparel manufacturing: driving the cutter.

10.

Company B:

1. Tubular knits-folding capability in software 2. Combine 2 pieces for cutdown
3. Blocking features (enlarge a piece for pattern machine or dye blocking for dye cutting.
4. Specify an alteration on a marker: made to measure and specify sizes and alteration on size.
5. Places large pieces first, then small ones automatically, or a combo of interactive and automatic.

Company C:
Do grading and marking: Device independent.
Size algorithm for placing pieces: Comparable to Company A. Fast and Efficient (literally instantaneous).

Company A:
1. Marrying groups of pieces
2. Apply "options" to a bundle
3. Dynamically alter pieces during marker making (made-to-measure).
4. Dynamically split pieces.
5. "Zoom in" to work closely
6. Measures between pieces and between pieces and border
7. Float small pieces in middle of hole between larger pieces.
8. Hocking, buffering, folding in software, alignment.

11 a.
Company B: Yes. Copy existing markers in automatic mode (reference capability). Alt. methods of teaching the computer to make a marker.
Faster turnaround time is more important than other benefits from automatic mode.
Company C:
Company A: Yes: Automatics in costing marker other approaches to AMM.
Benefits of AMM: Operators don't make a career of marker making anymore -- lack of skilled operators.
Tradeoffs between time and fabric utilization to make.

11 b.
Company B: Software subscription fee: does not change for upgrades.
Company A: 1st year: upgrades are fre After: free telephone support and newsletter.

12.
Company B: Improved drawing of pieces.
Company C: Automatic system - solve 50% of problems 100% of time, must be as good as a man can do.
Company A: n/a

13.
Company A: Capability of having in-house programmers to offer data translation for various computer system

"networking" within customer circle.